Environmental Regulation, Investment Timing, and Technology Choice

by

Wayne B. Gray
Clark University and NBER

and

Ronald J. Shadbegian
University of Massachusetts at Dartmouth

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Abstract

We test several hypotheses related to technology choice in the paper industry and the investment decision for existing plants, based on conversations with people and visits to paper mills. Our analysis uses technology choice data for 686 paper mills and annual investment data for 116 mills.

Technology choice is influenced by environmental regulation. New mills in states with strict environmental regulations tend not to employ more polluting technologies involving pulping. Differences between air and water pollution regulations also emerge, with the dirtiest technology in each medium avoiding states with the strictest regulations. The impacts are sizable: a one standard deviation increase in stringency is associated with several percentage point reductions in the probability of choosing a dirty technology.

State regulatory stringency and plant technology have little or no effect on annual investment spending at existing plants. However, pollution abatement investment is significantly related to productive (non-abatement) investment. Plants with high abatement investment spend less on productive capital. The magnitude of the impact corresponds to nearly complete crowding out of productive investment by abatement investment. Examining investment timing, we find that abatement and productive investment occurs in the same years, consistent with the high cost of shutting down a paper mill for renovations.

Wayne B. Gray
Department of Economics
Clark University
Worcester, MA 01610

Ronald J. Shadbegian
Department of Economics
University of Massachusetts, Dartmouth
North Dartmouth, MA 02747

1. Introduction

How much can economists learn from the 'real world'? Can plant visits and conversations with people in the industry suggest hypotheses to test, or modelling strategies? Is empirical research helped (or hindered) by understanding the institutional details? This paper addresses these issues, studying the impact of environmental regulation on investment decisions in the paper industry.

Environmental regulation in the U.S. has changed dramatically over the past thirty years. In the 1960s and before, environmental regulation was done by state and local agencies, usually without much active enforcement. With the establishment of the Environmental Protection Agency in the early 1970s, and the passage of the Clean Water and Clean Air Acts, the federal government took a lead role in regulation. State agencies are still heavily involved in setting standards for individual plants and enforcing those standards, backed now by the more serious penalties in the federal statutes. During the 1970s the focus was on basic air and water quality. In the 1980s there was more emphasis on toxic chemicals, both for cleaning up existing waste sites and for reducing emissions, with legislation at both the federal and state level.

These regulatory differences, both across states and over time, allow us to test for an impact of environmental regulation on investment decisions. We consider three possible connections between regulation and investment. First, the choice of which production technology to use in a new plant may be influenced by differences in the pollution characteristics of these technologies. Second, the allocation of capital investment across existing plants may be influenced by differences in the environmental stringency faced by those plants, interacting with the technology in place at those different plants. Third, a plant's investment in pollution abatement equipment may influence the timing and amount of investment in production equipment at the plant. If environmental regulation greatly affects profitability, it could influence all of these investment decisions.

We have chosen to study the pulp and paper industry, for a variety of reasons. The industry is a major polluter, with both air and water pollution concerns, and spends more on pollution abatement than most other manufacturing industries. Paper mills employ a variety of production technologies, which differ substantially in the pollution generated. Finally, we had already studied the industry using plant-level Census data, finding a significant impact of pollution abatement costs on productivity.

A central feature of the research project has been our contact with people in the paper industry. We visited ten paper mills in the Northeast, speaking with plant managers and environmental directors, along with visits to corporate headquarters and state and federal regulators. These contacts emphasized the importance of differences across plants, especially those based on the particular production technology at the plant. They underscored the difficulty of changing existing processes to accommodate new environmental concerns. We obtained practical information about how investment decisions are made, both at the plant and corporate level, which helped us model investment.

Our basic investment data comes from the Census Bureau's Longitudinal Research Database. We have annual investment data for 116 paper mills from the Annual Survey of Manufactures, beginning in 1972. Starting in 1979 we also have information on pollution abatement investment at 68 of the plants, so we can examine the relationship between productive and pollution abatement investment. We use an industry publication (the Lockwood Directory) to identify the production technology used at a larger sample of 686 plants for the technology choice analysis.

We find that new plants are increasingly less likely to use the 'dirtiest' technology over time, consistent with increases in environmental stringency over the period. There is also a significant connection between a plant's technology and state-level measures of regulatory stringency. New mills in states with strict environmental regulations are less likely to employ the most polluting technologies (those which involve pulping processes starting with raw wood). When we disaggregate the regulatory stringency by type of pollution, we find the expected results (though not always significant): the technology which emits the most air pollution is less commonly used in states with greater air pollution stringency, and vice versa for water pollution.

We find little evidence for an impact of state regulatory stringency or plant technology on annual investment spending at existing plants. However, we do find significant relationships between a plant's productive (non-abatement) investment spending and the amount and timing of pollution abatement investment. Investment tends to be lumpy, with pollution abatement and productive investment projects occurring simultaneously. This is consistent with plant mills having high fixed costs for shutting down during renovations. However, productive investment is lower in plants which do more pollution abatement investment over the period, indicating some 'crowding-out' of productive investment.

Section 2 describes the paper industry in more detail, including the reasons why different production technologies are differentially affected by regulation, along with a brief econometric model of the impact of regulation on technology choice and investment. Section 3 describes the data used for the analysis. Section 4 presents the results, with concluding remarks in Section 5.

2. Paper Industry Investment and Environmental Regulation

Before beginning our empirical work, we visited ten paper mills in the Northeast, owned by several different companies. We spoke with plant managers and environmental directors and toured their production facilities. We also spoke with environmental people at corporate headquarters, and both state and federal environmental regulators. This took several weeks of time, which might have been used collecting data and running regressions. What did we learn from this effort that might not have been obvious from basic economic theory or data analysis?

First, even though all paper mills belong to the same industry, they use many different production technologies. The first stage of the paper-making process is stock preparation, where some source of fiber (ranging from trees and wood chips to recycled cardboard or waste paper) is treated to separate out the fibers. The fibers are bleached in some cases to increase whiteness, and mixed with water to form a slurry. Those plants which begin with raw wood need some type of pulping process to separate the fibers in the wood from the lignin that binds them together. This can be done mechanically, with various types of chemicals, or some combination of the two. After the stock is prepared, it is more than 90% water, and needs to be dried: either deposited onto a rapidly-moving wire mesh (the fourdrinier process), or layered onto rotating drums (the cylinder process) before passing through a series of dryers to remove the water and create a continuous sheet of paper.

Second, these differences in production technology have important environmental consequences, especially in the pulping process. The most common pulping process in the U.S. today for handling raw wood is kraft (a.k.a. sulfate) chemical pulping. This process is relatively economical, because the wastewater from the pulping can be dried and burned in a recovery boiler, then treated to recover the chemicals for reuse. The older sulfite process used less expensive chemicals that were simply flushed into the river, generating substantial water pollution. In a curious irony, the chlorine bleaching process commonly used in kraft plants was identified in the early 1980s as a source of small amounts of dioxin in the wastewater, so the 'cleaner' kraft plants were then associated with a dangerous toxic substance. Some plants use mechanical pulping (like giant blenders) to separate the fibers. This avoids chemicals in the wastewater but is very energy-intensive, leading to increased air pollution concerns as these plants usually generate most of their own energy with large power boilers.

If the plant uses recycled cardboard or paper, it is easier to separate the fibers (add water and stir), but the presence of inks and other contaminants in the input makes it difficult to produce top-grade white paper. Deinking processes have been developed in recent years, and have been encouraged by paper recycling programs, but this generates sizable amounts of sludge, which aggravates waste disposal problems. The paper-making process itself causes fewer pollution problems, with less variation across plants. Some air pollution is associated with power-generating boilers needed to create steam for the dryers. Some water pollution results from residual fibers remaining in the water as the paper is dried, along with any chemicals used in the pulping process. Still, the pulping process is likely to provide the most important differences across plants from an environmental perspective.

Third, it is difficult or impossible to make major changes in the process. This is especially true for changes required by an environmental issue that was not recognized when the plant was designed. Older plants were sometimes built directly over a river, allowing spills to flow conveniently into the water for disposal; a major issue in current environmental regulation is containing spills and process upsets so that no pollutants enter the water. Changing one part of the process can affect other parts in indirect but expensive ways. For example, installing oxygen delignification (whitening the pulp and reducing the need for chlorine bleaching) in one plant would increase the flow of waste material to a recovery boiler by 3 percent. Because the capacity of the recovery boiler is designed to match exactly with the rest of the process, the plant would either need to spend tens of millions of dollars for a new, slightly larger, recovery boiler, or accept a 3 percent reduction in pulp production, which also costs millions, for what might seem to be a minor process change. This 'fixity' of the production process raises the stakes for the decision about which technology to adopt, especially given the possibility of unexpected changes in regulatory stringency over time.

Fourth, there are sizable differences across states in the stringency of environmental regulation. Federal EPA rules provide a framework for regulatory decisions, but individual plant-level decisions are usually made by state regulators. These decisions play a crucial role in the permit process, where there are often intensive negotiations about what level of environmental protection should be required before the permit is granted. Certain states tend to have stricter (or slower) permit writers than others. These permits are required before a new plant can begin operating, and may also be required for extensive changes to an existing plant. Some EPA rules also result in differences in regulatory stringency across states: in areas with air quality that fails to meet federal guidelines stricter emissions controls are required for all new plants.

Fifth, there is substantial scope for investment decisions to be affected by environmental regulation. Discussions with plant and corporate personnel indicate different procedures for small investment projects as compared with large renovations or new plants. Smaller projects are generally funded out of a capital budget for the plant, facing the plant manager with a choice between allocating funds for regulatory compliance or productivity enhancement. Plant managers reported that they have to give higher priority to 'legally required' projects and complained that productivity improvements are often crowded out by regulatory-driven investment.

Larger projects tend to undergo a lengthier review process, and may involve a direct competition between existing plants or new locations. They are more likely to require revisions in the environmental permits for the plant, which can add delays or uncertainty in those states with more stringent regulation. Given that much of the investment is financed with internal funds, and that industry demand is highly cyclical, a great premium is placed on bringing the new capacity on line as soon as possible. For this reason, delays and uncertainty are believed to be more important than the absolute level of stringency required by the permit, because of the costliness of delaying production. Some states are ruled out of consideration for new plants or expansions, due to past experience with regulatory permitting difficulties. These differences may be specific to particular technologies. For example, Maine has especially stringent rules regarding waste disposal, making it difficult to open a deinking plant that would generate substantial amounts of sludge.

Paper mills are highly capital intensive, making it very costly to shut down the plant for renovations, so they try to schedule different investment projects at the same time to minimize downtime. This should result in a 'lumpy' investment pattern for most plants, with occasional high levels of investment spending as major renovations are undertaken, followed by some years of substantially less investment activity.

Our visits gave us a much greater appreciation of the differences across plants, especially in their production technology, and the importance of institutional aspects of regulation leading to differences across states in regulatory stringency. This led directly to the current paper, in the sense that we were convinced of the importance of differences across plants in their production technologies, and the possibility of measuring these differences using published industry directories. We were also more confident that there might be important regulatory differences across states, large enough to affect investment decisions. Finally, the information about the investment process led us to consider a model of 'lumpy' investment decisions where timing matters, along with the possibility that abatement investment crowds out productive investment.

How does this viewpoint compare with what economists have done? The general issue that environmental regulation might affect investment decisions and technology choice has been around in the economic literature for some time, primarily in theoretical terms. The simplest case of an impact on technology choice would be a regulation that prohibited an especially 'dirty' production technique. Any regulatory standards that required reductions in emissions would tend to change the relative costs of different production techniques. Regulation might also tend to shift a firm's R&D effort. Devoting R&D to cleaning up existing production processes, combined with uncertainty about whether new processes will receive regulatory approval would tend to discourage the development of new production techniques. [1] On the other hand, regulations could force firms to develop new, clean production techniques, and

[1] See Hoerger et al. (1983) for an examination of how regulation slowed down R&D efforts in the chemical industry.

stimulate R&D spending. [2]

Viscusi (1983) shows that the increased uncertainty due to regulation, combined with irreversible investments, is likely to reduce investment. This would operate in addition to whatever investment disincentives arise from higher costs of production due to regulation. To the extent that regulations forced firms to adopt new production techniques and replace existing capital, there might be a positive impact of regulation on investment spending. However, this investment could be specifically directed at pollution abatement, and not increase the productive capacity of the plant.

Much of the existing research on the impact of environmental regulation examines its impact on productivity. This research has tended to find a significant, though not always overwhelmingly large, connection between regulation and productivity.[3] There has also been some work on the connection between environmental regulation and plant openings and closings. An analysis of steel plant closing decisions (Deily and Gray (1991) found that steel mills facing more air pollution enforcement were more likely to be closed. A state-level analysis of new plant openings (Gray (1997)) also indicated a

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[2] This is a main element of the 'Porter' hypothesis that properly-designed environmental regulations could actually increase, rather than reduce, firms' profitability (Porter (1990, 1991)).

[3] Studies with industry-level data include Barbera and McConnell (1986) and Gray (1986,1987); plant-level data studies include Gollop and Roberts (1983) and Gray and Shadbegian (1995).

significant negative relationship between a state's environmental regulation and the number of new plants opened in the state, though other studies (e.g. Bartik (1988)) have found smaller impacts. Thus we have some indication that environmental regulation may influence business decisions such as investment, but that such influences are likely to be small.

Let us consider the model of technology choice slightly more formally. Suppose that a company is planning to establish a new plant (i) in a particular state (s) at a particular time (t). There are a set of available technologies (j) among which the firm will choose. Each technology has an associated profitability (A_{ij}) which depends on regulatory factors (R_{st}) and other observable state-specific factors (X_{st}), along with unobserved plant-specific influences ($,_{ij}$). The firm chooses the most profitable technology, leading to a multinomial logit model:

$$
\begin{aligned}
\Pi_{i1} &= f\left(\sum_k \beta_{r1k} R_{stk} + \sum_m \beta_{x1m} X_{stm} + \epsilon_{i1}\right) \\
&\quad \ldots \\
\Pi_{iJ} &= f\left(\sum_k \beta_{rJk} R_{stk} + \sum_m \beta_{xJm} X_{stm} + \epsilon_{iJ}\right)
\end{aligned}
$$

$$with \;\; T_i = n \;\; if \;\; \Pi_{in} \geq \Pi_{ij} \;\; for\; j = 1, \ldots, J.$$

(1)

The state-specific control variables X include energy prices, likely to affect the more energy-intensive mechanical pulping process, the availability of commercial timber, affecting all of the pulping methods, and population density, affecting recycled paper processes through the relative availability of wastepaper.

We should note a few possible concerns with this model. First, there could be different sets of technologies available at different times, which would complicate the selection process. As it happens, all of the technologies considered here were in use by the earliest observation of plants in 1960.[4] Second, the profitability of a plant should be the expected profitability over the plant's lifetime, so the firm's expectations about future R and X values for the plant would enter the equation. We rely on the high degree of persistence in cross-state differences for our variables, and assume static expectations by firms when choosing technology. Finally, we should note a general limitation on our regulatory data, since it affects the types of analysis we can perform throughout the paper. Only our overall regulatory stringency measure is truly panel in nature, extending back into the 1960s: the state's Congressional delegation's voting record on environmental issues. The media-specific regulatory measures we use are cross-sectional ones, dating from

[4] There is technological change associated with each technique over time, but the broad categories we will be considering - kraft, sulfite (and other chemical methods), mechanical, and recycled - were all widely available by 1960. In a broader time frame, recycled is the oldest (the earliest U.S. paper mills used recycled rags), sulfite and mechanical are also relatively old, and kraft is somewhat newer - while the use of recycled inputs to produce high-quality white paper, by 'deinking' wastepaper, is the newest technology of all.

the mid- to late-1980s. Earlier work (Gray (1995)) examined different measures of regulatory stringency, finding that differences across states were fairly stable over time. This may reduce some concerns about using 1980s regulation to explain 1960s technology choices, but this is something we need to assume, not something we can test.

As with the technology choice decision, we now consider the investment allocation decision more formally, with current investment depending on the timing of past investment and other control variables. Since it is costly to shut down the mill for investment, we would expect intermittent investment, yielding negative coefficients on lagged investment. With many investment projects taking more than one year to complete, we might expect to find a positive impact for last year's investment spending on this year's spending. We use I_{it} to represent investment in plant i at time t and $I^{*}_{i,t-s}$ to represent past investment at this plant s years earlier, with other control variables similar to those included in equation (1):

$$(2)\ I_{it} = f(\sum_k \beta_{rk} R_{itk} + \sum_m \beta_{xm} X_{itm} + \sum_s \gamma_s I^*_{i,t-s} + \epsilon_{it})$$

In some analyses we use the plant's investment rate, dividing each year's investment by the start-of-year capital stock. In other analyses we concentrate on major investment projects, replacing the plant's annual investment spending with a dummy variable for 'large' investments (this part of the analysis follows that done by Cooper et. al. (1995)). This removes the need to scale the investment measure by plant size, but raises other concerns, including the use of probit or logit analyses in a panel context. We estimate a fixed-effects logit model, while Cooper et. al. used a linear probability model.

The panel nature of the data, while providing an opportunity to estimate fixed-effects models, may make it difficult to estimate impacts for some of the explanatory variables. As noted above, the media-specific measures have only cross-section variation, and the other variables have limited time-series variation. This tends to make the within-plant fixed-effect analyses yield imprecise results.

3. Data and Econometric Issues

The investment data for the project comes from the Longitudinal Research Database (LRD) containing information from the Annual Survey of Manufacturers (ASM), linked together for individual plants over time (for a more detailed description of the LRD data, see McGuckin and Pascoe (1988)). We use annual information on new capital investment spending from 1972 to 1990.

This is divided by the nominal value of the plant's capital stock to calculate the plant's investment rate.[5] In earlier work examining the impact of regulation on productivity (Gray and Shadbegian (1995)) we prepared a dataset of 116 paper industry plants with continuous ASM data over the 1972-1990 period, and we use the same sample of plants here.

We combine this LRD data with two other plant-level data sources. First is the Lockwood Directory, an annual directory of pulp and paper mills. We begin with a list of several hundred paper mills, prepared for an earlier research project. Lockwood data from several different years is examined, to see in which year the plant first appeared. This year is used to indicate the approximate 'vintage' of the plant. The Lockwood data also includes information on the production technology being used at each mill: whether the mill uses raw wood or recycled inputs, and how the raw wood is pulped. The combination of vintage and technology is used for the analysis of technology choice, with a total of 686 plants. This technology information is also added to the LRD data, using plant name and address information, for the 116 plants in the investment analysis.

Our final plant-level data source is the Pollution Abatement

[5] In earlier research on productivity with these plants we created real capital stock measures for each plant, using the perpetual inventory method, based on gross book value in an initial year and the plant's annual investment flows. We multiply this real capital stock by a paper-industry specific investment deflator from Bartelsman and Gray (1996) to get a nominal value.

Costs and Expenditures (PACE) survey, conducted annually by the Census Bureau. This is sent to a subset of firms in the Annual Survey of Manufactures, concentrating on the high-pollution industries. Since paper mills tend to be large polluters, they are commonly present in the PACE data. Because the set of plants who complete the PACE survey each year is smaller than the ASM sample, and changes over time, there is some attrition in our sample when we require continuous PACE data. We have PACE data from 1979-1990 (except for 1987 when the survey wasn't performed), and wind up with a total of 68 plants with complete annual data on pollution abatement investment.

In addition to the plant-level data, we use a number of state-level explanatory variables for the analyses, taken from the Statistical Abstract. These include population density (POPDEN = thousands of people per square mile) and energy price (ENERGY = price per million BTU in thousands of 1982 dollars), which vary somewhat across states and over time. We also use a measure of the availability of timber (FOREST = million cubic feet of softwood growing stock, per square mile of state land area). To measure a tendency towards stringent environmental regulation, we use the pro-environment voting score for the state's Congressional delegation (VOTE). This was found to be significantly related to manufacturing plant location decisions in Gray (1997). The voting data has been calculated by the

League of Conservation Voters since 1970; we compiled our own measure for the 1960s from data in the Congressional Record.

To differentiate between air, water, and toxic pollution regulation we take three measures from the Green Index (Hall and Kerr (1991). The AIR index is the sum of a state's ranking on 18 measures of air quality (including the emissions of various air pollutants and violations of air quality standards, measured in the late 1980s). The WATER index is the percent of the state's population whose water quality failed at least one Safe Drinking Water Act test in 1987. The TOXIC index is how many (out of 9) specific laws regulating toxic waste are in place in the late 1980s (for example, strict Superfund liability or 'right-to-know' laws). The AIR and WATER indices depend on states with worse pollution problems having stricter regulations, while the TOXIC index measures regulatory stringency directly. Since all of the Green Index measures date from the late 1980s, we have to rely on the cross-state differences remaining relatively fixed throughout the period (this consistency over time was found for other state regulatory measures in Gray (1995)).[6]

4. Estimation Results

[6] Other regulatory measures were considered, from the Green Index and other sources. The results were usually similar to those presented here, although a few showed differences (for example, an alternative index of state water pollution problems used in an earlier version of this paper gave positive, rather than negative, signs in the technology choice analysis).

We begin with the analysis of technology choice. Here we have assigned the plants to five technology categories: kraft, sulfite (including 'other' chemical and semichemical), mechanical, deinking, and other. The 'other' category consists primarily of mills that do not do their own pulping, but either purchase pulp from others or use recycled inputs, but not the more sophisticated deinking process. These 'other' plants tend to be small and less sophisticated, producing lower-quality products. The means and standard deviations of the variables used in the analysis are presented in Table 1. Note that two-thirds of the plants in the sample already existed in 1960 (since YR6070 and YR7095 only add up to .33).

Table 2 shows the results of a multinomial logit analyses of technology choice, with the 'other' category being the base group. Of the three control variables, population density and energy prices have little impact, while plants with pulping processes are more likely in states with more commercial forests. Greater regulatory stringency, as measured by VOTE, makes it less likely that a plant will use any of the three pulping technologies. To put these coefficients in perspective, a one standard deviation (19.119) increase in VOTE is associated with a reduction in the probability of choosing kraft technology of 7.9 percentage points (a large fraction of the 19.2 percent of plants that use kraft pulping). The comparable magnitudes for the other pulping technologies are 2.3 percent for sulfite and 1.5 percent for mechanical. Finally, the vintage coefficients are consistent with regulatory changes during the period. Later in the period we had both increased regulatory stringency, making the heavily-polluting sulfite mills less attractive, and policies to promote paper recycling, encouraging deinking mills.

Table 3 replaces the single regulatory stringency measure, VOTE, with three media-specific measures, AIR, WATER, and TOXIC. We find that, as expected, mechanical pulping is less likely in states with greater air pollution problems, while sulfite pulping is less likely in states with water pollution problems. All three pulping technologies are less likely where states have stricter regulations on toxic waste. This may reflect generally more stringent environmental regulations in those states with strict toxic waste regulations. Considering the magnitudes of these effects, a one standard deviation increase in AIR is associated with a 6.5 percent lower probability of using mechanical pulping. The comparable figure for WATER and sulfite pulping is 2.5 percent. For TOXIC, the comparable percentage reductions are 7.9 for kraft, 1.7 for sulfite, and 3.5 for mechanical pulping. The results for the other control variables are similar to those in Table 2, including the tendency for more deinking plants and fewer sulfite plants in later years.

One possible concern with this analysis is that most of the plants were established before 1960, when environmental regulations were considerably less stringent. Therefore Tables 4 and 5 repeat the analyses for the subsample of 227 plants established after 1960. The results are similar to those found earlier: pulping processes are less common in states with more stringent environmental regulation, with mechanical pulping being more sensitive to air and sulfite pulping being more sensitive to water, while all three pulping processes are sensitive to toxic regulation. The impacts on technology choice probabilities are similar to those calculated earlier, except that mechanical pulping is substantially more sensitive to VOTE and TOXIC. The control variables have similar coefficients to those in the earlier tables. The apparently large changes in the year coefficients are due to the change in base group from 'pre-1960 plants' in the earlier tables to '1960-1970 plants' in these tables.

We next turn to the analysis of the investment decision, with means and standard deviations presented in Table 6. Three different measures of investment spending are used in the analysis. IRATE reflects the quantity of investment being done at the plant, relative to the plant's capital stock. IDUM1 and IDUM2 are dummy variables, using different cutoff values to define 'major' investments. IDUM1 is a 'relative' measure, identifying those years in which investment exceeds 250% of the plant's median annual investment over the sample period. IDUM2 is an 'absolute' measure, identifying those years in which new investment exceeds 20 percent of the plant's existing capital stock.

We use two samples of plants in this analysis. The full sample of 116 plants is used for the basic analysis, examining whether technology or state regulatory stringency affect annual investment. Not all of these plants have complete information about pollution abatement capital expenditures from the Census PACE survey. To analyze the impact of pollution abatement investment on other investment, we also construct a PACE subsample for 68 plants with complete PACE information. In this subsample, we measure two aspects of pollution abatement investment. PACEDUM reflects the timing of abatement investment, identifying those years with more than $500,000 of abatement investment at the plant. PACERAT is a cross-sectional variable, dividing the plant's abatement investment over the entire period by its total investment over the period. This reflects the extent to which a large part of the plant's investment spending had to be directed towards pollution abatement over the entire period.[7] In the PACE subsample, we also adjust the dependent

[7] An alternative ratio for abatement intensity would divide abatement investment by the total plant capital stock. Because nearly all large investment projects include some pollution abatement component, high-investment plants also tend to be high-abatement plants by this measure. This leads to a positive PACERAT coefficient in the regressions, rather than the expected negative coefficient which we find here.

variables (investment measures IRATE, IDUM1, and IDUM2) by subtracting off abatement investment, so that the dependent variables represent only 'productive' investment.

We link in technology data from the Lockwood Directory, given here with technology dummies (we present only approximate values for the technology variables in Table 6 to avoid disclosing the exact number of plants in each technology category, for Census confidentiality purposes). We include state-specific explanatory variables (ENERGY and VOTE) in the data. For each of the technologies, we consider their interaction with the variable expected to be most strongly influential: energy prices for mechanical plants, regulation for sulfite/semichemical and deinking, and post-1984 for kraft (to capture recent concerns about dioxin emissions).

Table 7 presents both ordinary least squares and fixed-effects models of the investment rate at a plant. The past history of investment at the plant (ILAGs) provide a substantial amount of explanatory power. The past year's investment is strongly positive, presumably because one investment project often spans parts of two calendar years, so it could be reported in consecutive ASM surveys. Longer lags tend to be negative, especially in the fixed-effects models.[8] These past investment

[8] These negative values may be at least partly an artifact of the analysis. Since the fixed-effect model is equivalent to subtracting off the average of all other years, having had lots of investment in some other year (captured by ILAG) will subtract off a larger value, making the coefficient negative.

history variables are included in all subsequent analyses, although we omit them from the tables to save space. The ILAG coefficient estimates in later analyses are very similar to those shown in Table 7.

High energy prices tend to discourage investment in the cross section analysis, but are not significant in the fixed-effects model. However, the interactions of technology and energy prices are significant in the expected way, with mechanical plants being more sensitive to energy prices in the fixed-effect models. The regulatory variables show no effect, either by themselves or interacted with other variables.

Table 8 and 9 present the same type of analysis, although in this case we have binary dependent variables (IDUM1 and IDUM2) so we need to use a logit model (and a fixed-effects logit) rather than linear regression.[9] The energy and regulatory measures show very little connection to investment spending in the logit models.

Table 10 adds the technology dummies to the investment model, to see whether certain types of plants are more or less likely to get investment. We cannot use the fixed-effects models

[9] For the fixed-effects logit analysis, we use the procedure provided in LIMDEP. This procedure allows only 10 years of data, due to space constraints, so we must drop 2 years. The results are not especially sensitive to the choice of years to drop, nor are the other analyses affected substantially by dropping two years of data. In the results reported here, we dropped 1983 and 1987, since those years have missing (1987) or problematic (1983) PACE information so they are the best years to drop from the Table 11 analysis.

in this case, since plant technology is fixed. The only plants that receive significantly greater investment are deinking plants. Since our investment data refers to the 1980s, this is consistent with the technology choice analysis, where deinking technology was a much more popular choice in more recent years. State regulation measures and interactions of regulation with technology again show little connection with investment.

Table 11 focusses on the smaller PACE subsample of plants, analyzing the relationship between PACE investment and 'productive' investment (recalling that the dependent variables in this table have had PACE subtracted off). We note that the other explanatory variables (ENERGY and VOTE) show little impact on investment.

The two PACE variables identify very different aspects of pollution abatement's connection with investment. Our measure of abatement investment timing, PACEDUM, is positively related to investment spending (although only significant for IRATE). This is consistent with the high costs associated with shutting down a paper mill for renovations, and was reflected in our conversations with people at paper mills. Plants tend to 'save up' their investment projects when possible, and do them simultaneously. The magnitude of the PACEDUM coefficient implies a fairly large connection. If we compare a year with a big PACE investment with a 'non-PACE' year, we get a predicted difference in IRATE of 0.025 or more between them, about one-quarter of the mean value of IRATE in our sample.

Our measure of abatement intensity for the plant, PACERAT, is negatively associated with investment spending. Plants which have focussed their investment spending on pollution abatement have less money available for other investment spending. This can only be tested cross-sectionally, since PACERAT has only cross-sectional variation. This result is consistent with our conversations with paper industry people, who viewed abatement investment as 'crowding out' productivity-enhancing investment. It goes against the proposition that environmental regulations induce business to upgrade their productive capital stock more rapidly, expanding total investment.

Consider what the magnitude of the PACERAT coefficient (around -.1) means, assuming pollution abatement investment is $1 million, total investment is $11 million, and capital stock is $100 million. Productive investment would be $10 million, so IRATE and PACERAT would each be .1, roughly corresponding to the sample means. Doubling pollution abatement investment to $2 million would increase PACERAT from .1 to .2. This would be predicted to reduce IRATE by .01 from .1 to .09, corresponding to $9 million of productive investment. We would get complete crowding out of productive investment by pollution abatement investment, with total investment remaining at $11 million.

5. Conclusions

Based on our plant visits and conversations with people in the paper industry, we examine the impact of environmental regulation on two aspects of the investment decision for paper mills: the specific production technology installed in a new mill, and annual investment spending at existing mills. We find that plants in more stringent states are less likely to incorporate the dirtier production technologies. Looking at different types of pollution, we find that mechanical pulping, which generates more air pollution, is less likely in states with stricter air regulations. Sulfite pulping, the most water pollution intensive, is less likely in states with stricter water regulation. The magnitudes of these impacts are sizable, with one standard deviation increases in stringency associated with reductions in choice probabilities of several percentage points. We also find changes in technology choice over time consistent with changes in environmental regulation. We get similar results when we focus on the subsample of paper mills opened after 1960.

We find little or no impact of state regulatory stringency or plant technology on annual investment spending. This may reflect a tendency for existing plants to be kept operating, especially since older plants are often exempt from newer regulations. We do find significant connections between pollution abatement investment and productive (non-abatement) investment. Plants with high abatement investment spend less on productive capital. The magnitude of the impact suggests nearly complete crowding out of productive investment by abatement investment. When we look at the timing of investment spending, pollution abatement and productive investments tend to be concentrated in the same years, consistent with the high cost of shutting down a paper mill for renovations. In future research we plan to examine the impacts of regulation and technology on productivity and emissions at these paper mills.

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Table 1
Technology Choice Dataset
Summary Statistics
Mean (std dev)
(686 plants)

TECH	1.851	(1.177)	Technology index (1-5)

categories:

0.192	KRAFT	kraft
0.138	SULF	sulphite/semichemical
0.140	MECH	mechanical
0.032	DEINK	deinking
0.498	other/recycled <base group in multinomial logit>	

YR6070	0.166	(0.373)	1960< plant birth <=1970
YR7095	0.165	(0.371)	1970< plant birth <=1995
VOTE	51.259	(19.119)	Congressional voting pro-environment
AIR	32.210	(12.296)	Air pollution problem index
WATER	13.649	(18.781)	Pct. of population failing Safe Drinking Water Act requirements
TOXIC	4.239	(2.063)	Toxic substance regulation index
POPDEN	6.103	(48.720)	state population density (1000/sq mi)
ENERGY	0.171	(1.042)	state energy prices ($/MBTU)
FOREST	30.254	(12.391)	Commercially available softwood

Sources

Lockwood Directory : TECH, YR6070, YR7095.

League of Conservation Voters : VOTE.

Green Index : AIR, WATER, TOXIC.

Statistical Abstract : POPDEN, ENERGY , FOREST.

Table 2
Technology Choice - All Plants
Single Regulatory Stringency Measure
Multinomial Logit
(N=686)

Choice:	KRAFT	SULF	MECH	DEINK
CONSTANT	0.314	-0.387	-0.905**	-3.416***
	(0.346)	(0.372)	(0.418)	(0.875)
POPDEN	-0.006	-0.019	-0.005	-0.004
	(0.013)	(0.027)	(0.006)	(0.006)
FOREST	0.021***	0.026***	0.014**	-0.020
	(0.005)	(0.004)	(0.006)	(0.020)
ENERGY	0.180	0.467	0.316	0.198
	(0.318)	(0.538)	(0.209)	(0.230)
VOTE	-0.046***	-0.023***	-0.021***	-0.002
	(0.007)	(0.007)	(0.007)	(0.013)
YR6070	0.352	-1.473***	0.387	0.785
	(0.299)	(0.465)	(0.332)	(0.725)
YR7095	-0.180	-1.397***	-0.316	1.863***
	(0.350)	(0.462)	(0.414)	(0.567)
LOG-L=	-748.522			

Standard errors in parentheses.

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 3
Technology Choice - All Plants
Multiple-Media Stringency Measures
Multinomial Logit
(N=686)

Choice:	KRAFT	SULF	MECH	DEINK
CONSTANT	0.357	-0.391	1.437**	-4.941***
	(0.590)	(0.611)	(0.605)	(1.364)
POPDEN	-0.009	-0.022	-0.006	-0.005
	(0.014)	(0.028)	(0.008)	(0.006)
FOREST	0.033***	0.033***	0.009	-0.009
	(0.007)	(0.007)	(0.008)	(0.021)
ENERGY	0.293	0.544	0.372	0.233
	(0.333)	(0.554)	(0.241)	(0.226)
AIR	-0.020	-0.009	-0.065***	0.028
	(0.013)	(0.014)	(0.014)	(0.026)
WATER	-0.010	-0.015*	-0.009	0.014
	(0.008)	(0.009)	(0.008)	(0.010)
TOXIC	-0.430***	-0.199***	-0.312***	0.011
	(0.070)	(0.069)	(0.078)	(0.131)
YR6070	0.697**	-1.339***	0.424	0.834
	(0.290)	(0.461)	(0.334)	(0.715)
YR7095	-0.097	-1.368***	-0.336	1.949***
	(0.349)	(0.460)	(0.420)	(0.575)
LOG-L=	-736.921			

Standard errors in parentheses.

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 4
Technology Choice - Post-1960 Plants
Single Regulatory Stringency Measure
Multinomial Logit
(N=227)

Choice:	KRAFT	SULF	MECH	DEINK
CONSTANT	0.503	-1.608*	-0.042	-2.703***
	(0.492)	(0.840)	(0.576)	(0.979)
POPDEN	-0.007	-0.013	-0.003	-0.004
	(0.013)	(0.026)	(0.006)	(0.006)
FOREST	0.023**	0.040***	0.028***	-0.003
	(0.009)	(0.012)	(0.010)	(0.020)
ENERGY	0.210	0.366	0.299	0.192
	(0.330)	(0.550)	(0.205)	(0.228)
VOTE	-0.039***	-0.040**	-0.041***	-0.005
	(0.010)	(0.018)	(0.013)	(0.016)
YR7095	-0.584	0.166	-0.664	1.021
	(0.389)	(0.646)	(0.477)	(0.710)
LOG-L	-256.003			

Standard errors in parentheses.

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 5
Technology Choice - Post-1960 Plants
Multiple-Media Stringency Measures
Multinomial Logit
(N=227)

Choice:	KRAFT	SULF	MECH	DEINK
CONSTANT	0.569	-3.529*	0.987	-3.787**
	(0.937)	(2.067)	(0.974)	(1.597)
POPDEN	-0.011	-0.029	-0.004	-0.004
	(0.015)	(0.034)	(0.007)	(0.006)
FOREST	0.047***	0.069***	0.045***	0.011
	(0.012)	(0.019)	(0.014)	(0.021)
ENERGY	0.343	0.728	0.403*	0.259
	(0.362)	(0.679)	(0.230)	(0.227)
AIR	-0.004	0.035	-0.041*	0.012
	(0.019)	(0.040)	(0.022)	(0.031)
WATER	-0.022	-0.047	0.015	0.034**
	(0.022)	(0.042)	(0.012)	(0.013)
TOXIC	-0.458***	-0.236	-0.550***	-0.129
	(0.110)	(0.190)	(0.136)	(0.163)
YR7095	-0.844**	-0.043	-0.825	1.323*
	(0.403)	(0.661)	(0.500)	(0.795)
LOG-L	-243.156			

Standard errors in parentheses.

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 6
Investment Dataset
Summary Statistics
Mean (std dev)

	Full Sample (116 plants)		PACE Subsample (68 plants)	
Number of Obs	1392		816	
IRATE	0.127	(0.168)	0.101	(0.132)
IDUM1	0.287	(0.453)	0.235	(0.424)
IDUM2	0.166	(0.372)	0.120	(0.325)
PACEDUM			0.254	(0.435)
PACERAT			0.100	(0.108)
ENERGY	0.061	(0.015)	0.060	(0.013)
VOTE	0.594	(0.159)	0.579	(0.157)
KRAFT	0.4		0.5	
SULF	<0.1		<0.1	
MECH	<0.1		<0.1	
DEINK	<0.1		<0.1	
KRAFT*84	0.3	(0.4)	0.3	(0.5)
SULF*VOTE	5.1	(17.5)	4.9	(17.4)
MECH*ENERGY	0.5	(1.7)	0.6	(1.8)
DEINK*VOTE	5.7	(18.7)	2.9	(13.6)

Variable Definitions and Sources

Longitudinal Research Database, Census Bureau
IRATE = investment rate (new capital spending/capital stock)
IDUM1 =1 if investment >= 2.5*median annual investment for plant
IDUM2 =1 if investment >= .2*capital stock

Pollution Abatement Cost Survey, Census Bureau
PACEDUM =1 if pollution abatement investment >= $500,000
PACERAT = (pollution abatement investment)/(total investment), averaged over the entire sample period

Statistical Abstract
ENERGY = state-level energy prices

League of Conservation Voters
VOTE = Congress voting pro-environment

Lockwood Directory
KRAFT =1 if kraft mill
SULF =1 if sulfite or semi-chemical mill
MECH =1 if mechanical mill
DEINK =1 if deinking mill
<base group = other/recycled>

Table 7
Investment - Basic Model
Dep Var = IRATE
(Full Sample)

Method	OLS		Fixed-Effects	
ENERGY	-0.948**	-0.775**	-0.277	-0.228
	(0.404)	(0.363)	(1.057)	(0.575)
VOTE	0.064**	0.058*	-0.017	-0.021
	(0.031)	(0.033)	(0.060)	(0.062)
KRAFT*84		0.020*		0.025
		(0.012)		(0.016)
SULF*VOTE		0.005		-0.109
		(0.025)		(0.307)
MECH*ENERGY		0.289		-3.560**
		(0.255)		(1.546)
DEINK*VOTE		0.059**		-0.377
		(0.024)		(0.308)
ILAG1	0.164***	0.162***	0.125***	0.126***
	(0.013)	(0.013)	(0.013)	(0.013)
ILAG2	-0.003	-0.003	-0.028**	-0.027*
	(0.014)	(0.014)	(0.014)	(0.014)
ILAG3	0.050***	0.048***	0.022	0.020
	(0.014)	(0.014)	(0.014)	(0.014)
ILAG4	0.003	0.003	-0.018	-0.020
	(0.014)	(0.014)	(0.014)	(0.014)
ILAG5	0.015	0.013	-0.009	-0.007
	(0.014)	(0.014)	(0.014)	(0.014)
ILAG6	-0.003	-0.004	-0.023	-0.023*
	(0.014)	(0.014)	(0.015)	(0.015)
ILAG7	-0.016	-0.018	-0.048***	-0.048***
	(0.013)	(0.013)	(0.014)	(0.014)
R2	0.178	0.183	0.299	0.305
SSE	32.4002	32.2088	27.6178	27.4016
N	1392	1392	1392	1392

Standard errors in parentheses.

All models include constant term and year dummies.
ILAGt is t-year lagged value of IDUM2.

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 8
Investment - Basic Model
Dep Var = IDUM1
(Full Sample)

Method	Logit		Fixed-Effects Logit	
ENERGY	-1.190	5.323	-18.988	10.536
	(6.168)	(5.617)	(16.780)	(9.403)
VOTE	-0.273	-0.640	-1.150	-0.875
	(0.478)	(0.515)	(0.926)	(0.958)
KRAFT*84		0.040		-0.128
		(0.174)		(0.281)
SULF*VOTE		0.255		0.517
		(0.383)		(4.655)
MECH*ENERGY		5.060		-11.085
		(3.800)		(23.406)
DEINK*VOTE		0.430		-5.275
		(0.349)		(4.588)
LOG-L	-764.318	-764.045	-470.399	-471.424
N	1392	1392	1160	1160

Standard errors in parentheses.

All models include constant term and year dummies, and 7 ILAGn variables (lagged IDUM1 values).

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 9
Investment - Basic Model
Dep Var = IDUM2
(Full Sample)

Method	Logit		Fixed-Effects Logit	
ENERGY	-3.731	-7.364	8.861	-0.259
	(8.205)	(7.621)	(24.002)	(13.472)
VOTE	0.027	0.135	-0.822	-0.571
	(0.610)	(0.662)	(1.263)	(1.316)
KRAFT*84		0.054		-0.196
		(0.219)		(0.375)
SULF*VOTE		-0.257		-0.943
		(0.516)		(8.709)
MECH*ENERGY		-1.677		-57.436*
		(5.062)		(31.531)
DEINK*VOTE		0.420		-5.483
		(0.415)		(6.530)
LOG-L	-523.456	-523.09	-275.454	-273.852
N	1392	1392	1160	1160

Standard errors in parentheses.

All models include constant term and year dummies, and 7 ILAGn variables (lagged IDUM2 values).

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 10
Investment - Extended Model
Including Technology Dummies
(Full Sample)

Dep. Var.	IRATE		IDUM1		IDUM2	
Method	OLS		Logit		Logit	
Model	9.1	9.2	9.3	9.4	9.5	9.6
ENERGY	-0.746*	-0.696*	0.795	5.355	-2.716	-5.526
	(0.431)	(0.379)	(6.592)	(5.852)	(8.742)	(7.862)
VOTE	0.054	0.045	-0.624	-0.762	0.036	0.062
	(0.035)	(0.035)	(0.545)	(0.546)	(0.695)	(0.699)
KRAFT	0.007	-0.010	-0.083	-0.167	0.087	0.058
	(0.011)	(0.015)	(0.170)	(0.249)	(0.216)	(0.318)
MECH	0.020	0.132	0.238	0.168	0.008	1.824
	(0.016)	(0.083)	(0.242)	(1.254)	(0.316)	(1.527)
SULF	0.002	-0.020	0.060	-2.467	-0.125	-3.028
	(0.017)	(0.159)	(0.263)	(2.465)	(0.355)	(3.827)
DEINK	0.037**	-0.059	0.241	3.434	0.346	0.995
	(0.016)	(0.161)	(0.242)	(2.315)	(0.292)	(2.946)
KRAFT*84		0.028*		0.171		0.013
		(0.016)		(0.257)		(0.326)
SULF*VOTE		0.034		3.939		4.351
		(0.243)		(3.725)		(5.722)
MECH*ENERGY		-1.879		1.829		-31.220
		(1.356)		(20.390)		(25.541)
DEINK*VOTE		0.145		-4.781		-1.002
		(0.242)		(3.492)		(4.406)
R2	0.181	0.185				
SSE	32.260	32.130				
LOG-L			-762.907	-762.104	-522.479	-521.998
N	1392	1392	1392	1392	1392	1392

Standard errors in parentheses.

All models include constant term and year dummies, and 7 ILAGn variables (lagged IDUM2 values, except for the IDUM1 model which uses lagged IDUM1).

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level

Table 11
Investment - PACE Model
(PACE Subsample)

(Dep Var = IRATE)

Method	OLS	OLS	F.E.
PACERAT	-0.112***		
	(0.041)		
PACEDUM		0.027***	0.032***
		(0.010)	(0.012)
ENERGY	-0.406	-0.600	-1.200
	(0.475)	(0.475)	(1.300)
VOTE	0.013	0.040	-0.010
	(0.031)	(0.032)	(0.100)
R2	0.155	0.154	0.262
SSE	11.915	11.925	10.402
N	816	816	816

(Dep Var = IDUM1)

Method	Logit	Logit	F.E. Logit
PACERAT	-2.067**		
	(1.005)		
PACEDUM		-0.063	0.184
		(0.204)	(0.274)
ENERGY	7.346	5.984	4.352
	(9.667)	(9.553)	(27.393)
VOTE	-0.819	-0.679	-3.193**
	(0.636)	(0.640)	(1.485)
LOG-L	-401.718	-404.105	-238.059
N	816	816	680

Table 11 (cont.)
Investment - PACE Model
(PACE Subsample)

(Dep Var = IDUM2)

Method	OLS	OLS	F.E.
PACERAT	-2.495		
	(1.678)		
PACEDUM		0.396	0.251
		(0.267)	(0.363)
ENERGY	6.110	3.875	-5.106
	(13.087)	(13.025)	(38.929)
VOTE	-0.679	-0.211	-0.250
	(0.876)	(0.886)	(1.983)
LOG-L	-244.500	-244.767	-120.448
N	816	816	680

Standard errors in parentheses.

All models include constant term and year dummies, and 7 ILAGn variables (lagged IDUM2 values, except for the IDUM1 models which use lagged IDUM1).

*** = significant at 1% level
** = significant at 5% level
* = significant at 10% level